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Assessment of Institutional Linkages and Information Flow within the Agricultural Knowledge and Innovation: Case of Dakahlia Governorate, Egypt

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Abstract: Institutional linkages and information flow between agricultural organizations play a critical role in addressing sustainability issues and promoting agrarian innovation. The aim of this study was to evaluate institutional relations and information between the various actors within the agricultural knowledge and information system (AKIS). The study focused on eight actors within the AKIS in Dakahlia governorate of Egypt, namely policy, extension, research, agricultural cooperatives, higher education, secondary education, credit, and the private sector. Thus, the survey sample included 11 representatives of each actor with 88 respondents. Data were collected by a standardized questionnaire distributed online. The graph theoretical technique was used for the quantitative assessment of information flow and institutional linkages established among actors. The findings indicated that agricultural extension ranked first about their real cause and effect on the rest of the system, having a value of 7.95. Two critical information pathways within the AKIS sustained innovation outcomes: (1) higher education–extension–agricultural cooperatives, (2) research–extension–agricultural cooperatives. The results also revealed that agricultural cooperatives ranked second after the extension component on the extent of supplying information to other members in the AKIS, with a value of 4.8. In contrast, the highest component received information from other components (7.6). By analyzing institutional linkages and information flow, this article gives insights to policymakers on the mechanisms that still need to be strengthened and the information gaps between actors to address the challenges of sustainable rural development.

Keywords: innovation; institutional linkages; information flow; agricultural extension; cooperatives; sustainability; graph-theoretical technique; Egypt

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1. Introduction

Globally, the agriculture sector has been facing several challenges affecting poverty, food security, and the overall sustainability of agricultural systems [1]. The world population will exceed 9.6 billion in 2052 compared to 6.7 billion in 2018 [2], which negatively affects natural resources, causes increased greenhouse gas emissions, and further deforestation and land degradation due to the need for increased food production by 70% to supply food for the growing population [3]. Moreover, the adverse consequences of climate change, biodiversity loss, drought and desertification, and the COVID-19 pandemic constitute many challenges to food and agriculture [4,5]. Because of the insufficient agricultural production to feed the world's population, the number of people exposed to food shortage reached 821 million in 2018, 82% of whom were in rural areas, and most of them relied on agriculture for their livelihoods [6,7]. Additionally, about two billion people worldwide suffer from moderate or severe food insecurity [8]. Such trends highlight that the colossal challenge of achieving the second sustainable development goal of the United Nations (zero hunger by 2030) is still present [9].

There is an urgent need for innovations across the agricultural systems to address these challenges [2,10,11]. According to the Organisation for Economic Co-operation and Development (OECD [12]), innovations are the essential drivers of competitiveness, productivity, profitability, and, finally, the sustainability of the agriculture sector. Agricultural innovations include new equipment knowledge and technologies, enhanced seeds, vaccines, breeding techniques, fertilizers and pesticides, and other farm inputs. They also contain new approaches for accessing new markets and products, management improvements, and the practice of quality protocols [13]. Innovation processes involve a complex and dynamic interaction of multiple actors, actions, and activities along the stages of the food supply chain: production, processing, distribution, retail, and consumption or disposal [14]. Therefore, the involvement of various stakeholders in co-innovation processes is critical to collaborate in solving complex problems jointly [14]. Thus, there is an urgent need to direct innovation to facilitate interconnectedness between societal and individual innovation processes and vice versa to form sustainable innovation processes [15]. The agricultural knowledge and innovation system (AKIS) may be the answer [16]. This framework has been popular as a holistic approach in the agricultural innovation literature, and many countries have used it in the policy documents of food and agricultural institutions [17].

The AKIS concept refers to a network of organizations, enterprises, and individuals and the interactions and linkages between them, engaged in all stages of knowledge development (generation, transformation, transmission, storage, retrieval, integration, diffusion, and utilization). Those persons and organizations work simultaneously to solve problems, make decisions, and promote innovation in the agriculture sector (6, 17, 29). This framework includes five main domains, namely (1) business and enterprise, (2) knowledge and education, (3) brokering organizations linking business and enterprise organizations with knowledge and education organizations, (4) public policy and informal institutions establishing the norms, rules, and cultural characteristics of a society, and (5) linkages with other sectors of the economy and other connections beyond the borders of the system, such as those with international actors (28). A well-developed AKIS possesses seven functions: (1) Knowledge development reflects the ability of the system to develop new knowledge for solving problems and sustaining outcomes [18]. This function occurs in public research institutions and may include agri-business or farmers [19]; (2) Network formation and knowledge diffusion involving forming networks and platforms between actors within the system [20] are crucial for the upscaling and outscoring of agricultural innovations [21]; (3) Entrepreneurial activities including the transformation of the new knowledge into specific actions to provide new business opportunities [22,23]. Illustratively, Turner et al. [24] have suggested that trying to change institutional structures or lobbying for the fund is an entrepreneurial activity within the AKIS (4) guidance of search centering on formulating innovation agendas to form a vision within the AKIS [25]. The objective of this vision is to orient other functions, such as knowledge development and entrepreneurial activities and setting priorities for other components at a country's regional or national levels [26]; (5) Formation of markets for new technologies such as niche markets and the enhancement of customers' awareness and promotion of demand for new products using communication information technologies [17,27]; (6) Resource mobilization for the financial and human capital needed to undertake all activities in the AKIS [28,29]; (7) Formation of legitimacy and counteracting resistance to lobby for resources and affect the innovation agenda [30,31].

An extensive literature on agricultural innovation has discovered that cooperatives play a crucial role in innovation intermediation because they link different actors, mobilize resources for agricultural and rural development in the interests of their members, and provide synergy in agricultural innovation efforts [32–36]. The role of cooperatives as innovation intermediaries may be due to the agricultural extension institutions, considered initially to be acting as a bridge between research and farmers. Still, extension services have expanded their mandate to act as advisory services providing to several institutions within the AKIS [37,38]. The literature stresses the relevance of performing two essential roles of intermediaries, i.e., knowledge intermediation and mobilizing resources, to uphold innovation processes as intermediaries [39,40]. Knowledge intermediation includes facilitating knowledge co-construction in knowledge production and use [39,41]. Schut et al. [42] have reported that enhancing knowledge co-construction requires conducting three functions by the intermediaries, such as articulating users' needs and demands, providing information responding to users' needs, and engaging with other actors. Likewise, intermediaries should foster conditions for innovation by playing other functions such as helping actors mobilize resources [43]. These functions are building visions on the scope and nature of innovations, constructing and managing networks with actors, and facilitating and joining in learning processes [44,45]. Nonetheless, these functions might affect intermediaries' positioning in the AKIS [46]. Thus, Klerkx and Leeuwis [47] have suggested that the legitimacy of innovation intermediaries could cause tensions due to accountability conflicts originating from multiple demands from different parties and the varying and conflicting interests among actors.

Encouraging linkages between innovation intermediaries and heterogeneous actors to improve intermediaries' functioning within the AKIS is critical to address sustainability issues [32]. Recently, the analysis of the actors' performance within the AKIS has increasingly focused on institutional linkages to underline working relationships established between two or more organizations [48], and flows or exchanges of information, technology, and resources among actors in the AKIS [49]. Institutional linkages, both horizontally within the same level and vertically across levels, are essential factors in organizations' sustainability [50,51] and agri-food chains [52,53]. Institutional linkages present several outcomes. Hence, Lockwood [54] has showed that well-connected actors show greater mutual respect and trust levels. Institutional linkages are critical to construct adaptive capacity, modifying institutional arrangements, changing practices, solving common problems, and joint-learning [55–57]. However, information flow is one of the essential determinants for effective institutional linkages within the AKIS [58] because the information flow ensures coordination and control activities among actors [59]. Additionally, the flow of information plays a strategic role when considering the interdependency and complexity of organizational resources [60]. A pressing need to recognize how to understand and manage processes better for receiving, storing, and retrieving information by the actors is critical to keep efficient information flows [61]. Many methodologies such as structured analysis [62,63], thematic analysis [64], functional decomposition [65], episodic communication channels in organizations [66], social network analysis [67], and graph-theoretical technique (GTT) [68,69] to analyze institutional linkages and information flow between organizations, are available in the literature. We used the GTT in our study.

Most existing research on the field of AKIS has centered on the organizations' functions and services, organizational structure, and evaluation of their performance, specifically under the context of Egypt. However, we have little information on how agricultural organizations interact with other actors in the AKIS and how information flow patterns may affect the organization's capacity to receive information, share it with others, and learn from it. The present study presents a quantitative assessment of institutional linkages and information flow among essential actors, such as agricultural cooperatives, policy, extension, secondary education, research, private sector, and credit in the regional AKIS in Egypt. The main objective of this study was to analyze the institutional linkage and information flow between these actors using the GTT approach. To achieve this goal, three objectives were suggested. First, evaluating institutional linkages. This objective aimed to assess the existence, strength, and type of linkages between actors. Furthermore, calculating the density of the linkage matrix between the components within the AKIS in the study area. Second, determining gaps and information pathways. By achieving this objective, the actors within the DG-AKIS are classified based on the total causal relations (cause and effect) between them. The critical linkages and vital gaps are determined, and the essential information pathways between actors are identified. Finally, assessing the information flow between actors within the AKIS. This objective is expected to assess the capacity of the actors in terms of receiving information, learning, and sharing it. The capacity matrix will further help in identifying the information flow structure for the supply and receipt actors within the AKIS in the study area.

The study's main research question was the following: what is the existing situation of institutional linkages and information flow between actors investigated within the AKIS in the study area? The following sub-questions contribute to the answer of the main research question:

- What is the current situation of institutional linkages between actors?
- What are the information pathways used to overcome the issue of information gaps between actors?
- What is the present situation of information flow between actors?

2. Materials and Methods

2.1. The Approach Followed

The present study adopted the GTT for assessing the institutional linkages and information flow between actors within the AKIS. Temel and his colleagues also developed and applied the GTT [68–75], which joined the two research fields: graph theory in discrete mathematics and systems analysis in engineering. The graph theory offers beneficial concepts and techniques in evaluating a system's properties [73]. Such concepts are subjects of discrete mathematics and may reflect the system's characteristics under investigation [75]. The GTT approach assumes that learning takes place in many parts of the system, and that knowledge generated in one place can be diffused to other places through active linkages between people and between the organizations [69]. This approach is used to investigate the key features of the links between the actors within the AKIS in the study area. Then, using these links, a cause–effect structure is established, and possible subsystems and interaction pathways are identified [70]. The GTT involves several steps, starting with the optimal system matrix passing through a coded linkages matrix, a refined matrix, adjusting matrix, cause–effect structure of adjusted matrix, and mechanisms matrix, and ends with density of the system [73]. All of these steps are detailed below.

2.1.1. Linkage Matrix

This paper presumes that the AKIS under investigation has four components, namely (A), (B), (C), and (D), to depict the linkage matrix of AKIS. Potential interactions among the four components are defined by pursuing the clockwise convention. In the off-diagonal cells of the matrix AKIS[I] (Figure 1), the components had one-to-one interaction between them. The first row and the first column included linkages of component (A). The term AB in the cell of the first row and the second column of AKIS[I] depicted that component A interacted with B, and A was the initiator of this interaction. Similarly, the term BA corresponded to the second row and the first column. Such interactions were between-components linkages. Nevertheless, this matrix denoted the linkages between the two actors through the pathways of binary linkages (e.g., ABC). The following formula gives the total number of k-edged pathways within the AKIS [70]:

$$\textbf{AKIS[I]} = \begin{pmatrix} \mathbf{A} & AB & AC & AD \\ BA & \mathbf{B} & BC & BD \\ HP & HR & \mathbf{C} & HS \\ SP & SR & SH & \mathbf{D} \end{pmatrix}$$

Figure 1. Linkage matrix (A virtual example).

n!/(n − k − 1)!, where n and k represent numbers of actors in the AKIS and the number of edges in a pathway, respectively.

In this example (Figure 1), the number of one-edged pathways in the AKIS[I] matrix is 4!/(4 − 1 − 1)! = 12, where n = 4 and k = 1.

2.1.2. Coding Linkage Matrix

The binary linkages in AKIS[I] are coded with 1 if the linkage exists and is critical for the investigation, and with 0 if the linkage does not exist or it exists at a negligible level, or the actor is unable to identify it [72]. The coded matrix AKIS[II] is in Figure 2A and visual format (Figure 2B).

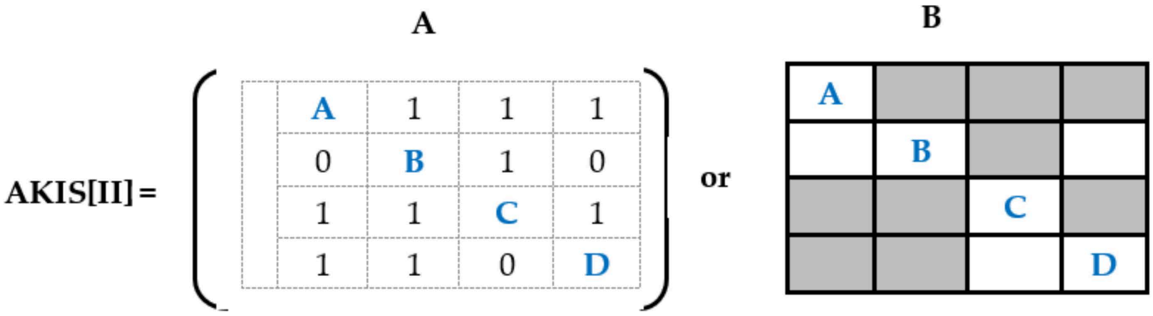

Figure 2. The coded linkage matrix (**A**) and its visual format (**B**) (A virtual example).

2.1.3. The Refinement of Matrix

The interactions in Figure 2 have hypothetical codes based on the strength of linkages on a three-point scale ranging from three for strong linkage to one for weak linkage (Figure 3A). Moreover, nonexistent linkages have the code of 0, as indicated in Figure 2 [72]. The visual format of the interactions in AKIS[III] (Figure 3B) displays white cells for nonexistent linkages, grey cells for weak linkages, black-lined cells for medium linkages, and heavily dark cells for solid linkages.

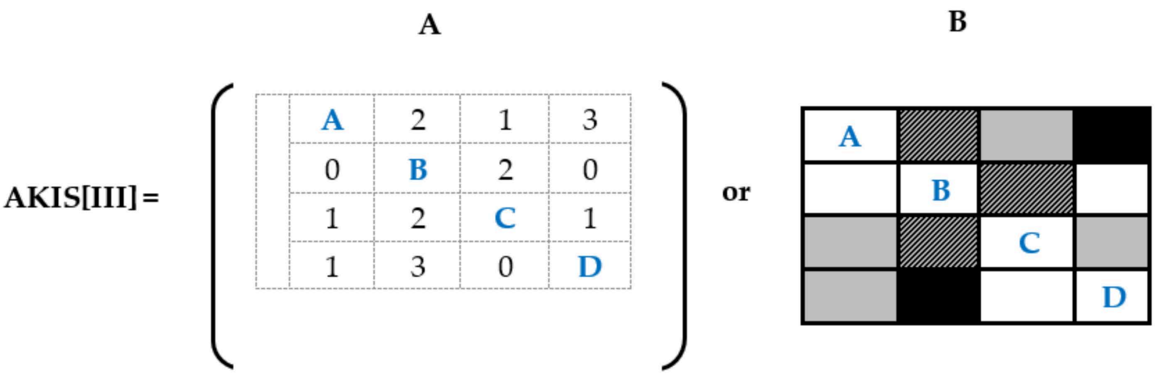

Figure 3. The refined linkage matrix (**A**) and its visual format (**B**) (A virtual example).

2.1.4. Adjusted Matrix

The refined matrix AKIS[III] (Figure 3) is adjusted by multiplying the strength of the linkage using the following scale: strong (s = 1), medium (m = 0.66), weak (w = 0.33), and none (n = 0), as shown in Figure 4. In AKIS[V] matrix (Figure 4), the linkages between components are transformed into the influences between them [73].

AKIS[V] =

A	1.32	0.33	3
0	**B**	1.32	0
0.33	1.32	**C**	0.33
0.33	3	0	**D**

Figure 4. The adjusted linkage matrix.

2.1.5. The Cause–Effect Structure of Matrix

The cause is the influence of a single actor on each of the other actors within the AKIS. The cause of specific actors to other actors is calculated by summing the raw values identified in the adjusted matrix AKIS[V] (Figure 4), where this specific actor is placed [73]. For instance, the first row in Figure 4 shows the extent of influence to all actors. However, the effect is the influence of each of the remaining actors on that specific actor. The impact of other actors on a specific actor is determined by summing the column values identified in the adjusted matrix AKIS[V], where this specific actor is placed [73]. For instance, the first column indicates the extent of all components' effect on component A.

2.1.6. Density of Matrix

The density (d) of the cause–effect structure of AKIS[V] is the percentage of existing binary linkages to the potential ones, and is calculated by the following formula [70]:

$d = b/[n(n-1)]$ with $1 \geq d \geq 0$, where b shows the total number of actual linkages, and n is the number of components of AKIS[V]. In this formula, the density of AKIS[V] is 0.75, b = 9, and n = 4. Fully identified structures (d = 1) denote that all the actors are connected.

2.1.7. Causal Relations Matrices

Determining the gaps and information pathways in the cause–effect relations is critical to grasp the desired changes within the AKIS. Establishing the dominant and dependent components in the system utilizes coordinates of cause and effect and requires having three matrices for the various types of linkages (weak, moderate, and strong). Causal relation matrices (CR) are given by the following formula [72]:

$CR = F * W$, where F represents the frequency of responses in each binary linkage, and W corresponds to the weight of linkage strength (strong (s = 3), medium (m = 2), weak (w = 1)). All three matrices are joined to form the total casual relation matrix between the components within the AKIS.

2.1.8. The Cause–Effect Structure of Causal Relations

The cause structure is calculated by adding the values of each row identified in the total casual matrix. In contrast, the effect structure is determined by summating the values of each column. Based on the values of the total casual relations, the characteristics of the components are described as follows: interactive component (its influence on the other component is equal to the effect of other components on it), the dominant components (cause > influence), and sub-ordinate components (cause < influence) [72].

2.1.9. Critical Information Gaps and Pathways

In this step, the reduced casual relations matrix is developed to specify critical information gaps or important causal relations. This matrix has five critical linkages among the interactive, dominant, and subordinate components. Information pathways are drawn among these components, where each pathway begins from the dominant components, passing by the interactive component, and culminates with the subordinate component [72].

2.1.10. The Information Flow Matrix

The refinement matrix (Figure 2) is converted to an information flow matrix to evaluate information flows and identify essential receivers and senders of the information within the system (Figure 5). Temel [68] has noted that this transformation requires measuring three indicators among the components, including capacities to receive information (θ), learn (λ), and share information. In the diagonal cells of the matrix, the capacity of components to learn information is placed, and their capacities to transmit and receive are placed in the off-diagonal cells of the information flow matrix. For instance, the capacity of component A to receive information from other components is θA, and its capacity to share information with others is σA, and learning information is λA. Thus, the function (σ^A θ^B) in the first row and the second column (Figure 5) refers to A's capacity to share information with B and receive information from it.

A(λ^A)	$\sigma^A \theta^B$	$\sigma^A \theta^C$	$\sigma^A \theta^D$
0	**B(λ^B)**	$\sigma^B \theta^C$	0
$\sigma^C \theta^A$	$\sigma^C \theta^B$	**C(λ^C)**	$\sigma^C \theta^D$
$\sigma^D \theta^A$	$\sigma^D \theta^B$	0	**D(λ^D)**

Figure 5. The information flow matrix.

2.1.11. The Capacity Matrix

The capacities to receive (θ), learn (λ), and share (σ) information to other organizations (Figure 6) are evaluated by the representatives of the AKIS, assigning 1 for strong capacity (denoted by s), 0.66 for medium (characterized by m), 0.33 for a weak (represented by w), 0 for the absence of capacity (denoted by n) [68]. By determining the values of the capacities, the capacity matrix of AKIS is drawn, as depicted in Figure 6 (A virtual example). Illustratively, the term σ^A θ^B in the first row and the second column is calculated according to the values of capacities (Figure 6A) and rounded to the nearest digit ($1 \times 0.66 = 0.7$) and so on for other linkages (Figure 6B).

A

A(s)	sm	ww	sm
0	**B(m)**	mm	0
wm	ms	**C(w)**	ss
ws	mm	0	**D(m)**

B

A(s)	0.7	0.1	0.7
0	**B(m)**	0.4	0
0.2	0.7	**C(w)**	1
0.3	0.4	0	**D(m)**

Figure 6. The capacity matrix (A virtual example). (**A**) represent the coded capacity matrix. (**B**) shows the values of capacities.

2.1.12. The Adjusted Capacity Matrix of Information Flow

The adjusted capacity matrix is the product of each cell in the capacity matrix of AKIS (Figure 6) (except the diagonal cells) with the corresponding cell in the progressive linkages matrix (Figure 2) [71]. These calculations lead to the following effective capacity-weighted matrix of AKIS (Figure 7). This matrix shows an information flow structure, presenting how fluid the information in the system is.

A(s)	1.4	0.1	2.1
0	**B(m)**	0.8	0
0.2	1.4	**C(w)**	1
0.3	1.2	0	**D(m)**

Figure 7. The adjusted capacity matrix of information flow.

2.1.13. The Information Flow Structure

The supply–receipt structure specifies the information flow between components. The supply is the degree of the single component's information supplements to each remaining component. Temel [71] noted that the supply is the sum of each row in the adjusted matrix (Figure 7). For instance, combining the values in the first row in the adjusted matrix (Figure 7) indicates that A's score as an information supplier is 3.6. However, the receipt is the information reception of a single component from each component. It is the sum of each column in the adjusted matrix (Figure 7) [71]. Illustratively, the combination of values in the first column depicts that the score of component A, as an information receiver, is about 0.5.

2.2. AKIS in the Study Area

In the northeast part of Egypt, this study was conducted in the Dakahlia governorate (31.3402° N, 32.0725° E), shown in Figure 8. The governorate covers an area of 3900 km^2 and has a population of approximately 7,000,000 in 22 districts. The average temperature fluctuates between 15 and 33 °C, with a mean annual value of 20 °C, and the total annual rainfall is 57 mm [76]. Cultivated agricultural lands are about 37% of the total area of the governorate. The essential crops consist of wheat, rice, Egyptian clover, corn, cotton, sugar beet, vegetables, and citrus fruits [77].

The AKIS in Dakhalia governorate (hereafter referred to as the DG-AKIS) included multiple actors, both in the public and private sectors. As shown in Figure 8, the framework is comprised of three main domains: research and education institutions, intermediaries/bridging institutions, and farmer enterprises. These domains include the main components in the AKIS that interact in certain ways to facilitate agricultural innovation development and access. However, their interactions are influenced by supply–demand structure, support structure, and policy processes [78]. At the community level, farmers and farmer cooperatives are the main actors of the farmer enterprises' domain. On the other hand, multiple actors are included in intermediaries' domain, such as the private sector, governmental extension, and non-governmental organizations. Agricultural research stations and Mansoura University are the key actors involved in the research and education domain. In terms of the strength of linkages between actors, Figure 8 shows that the majority of these linkages between actors were seen to be weak (brown arrows) and that only few linkages were perceived to be strong (black arrows), whereas non-existent linkages were observed in some linkages (yellow arrows) [79].

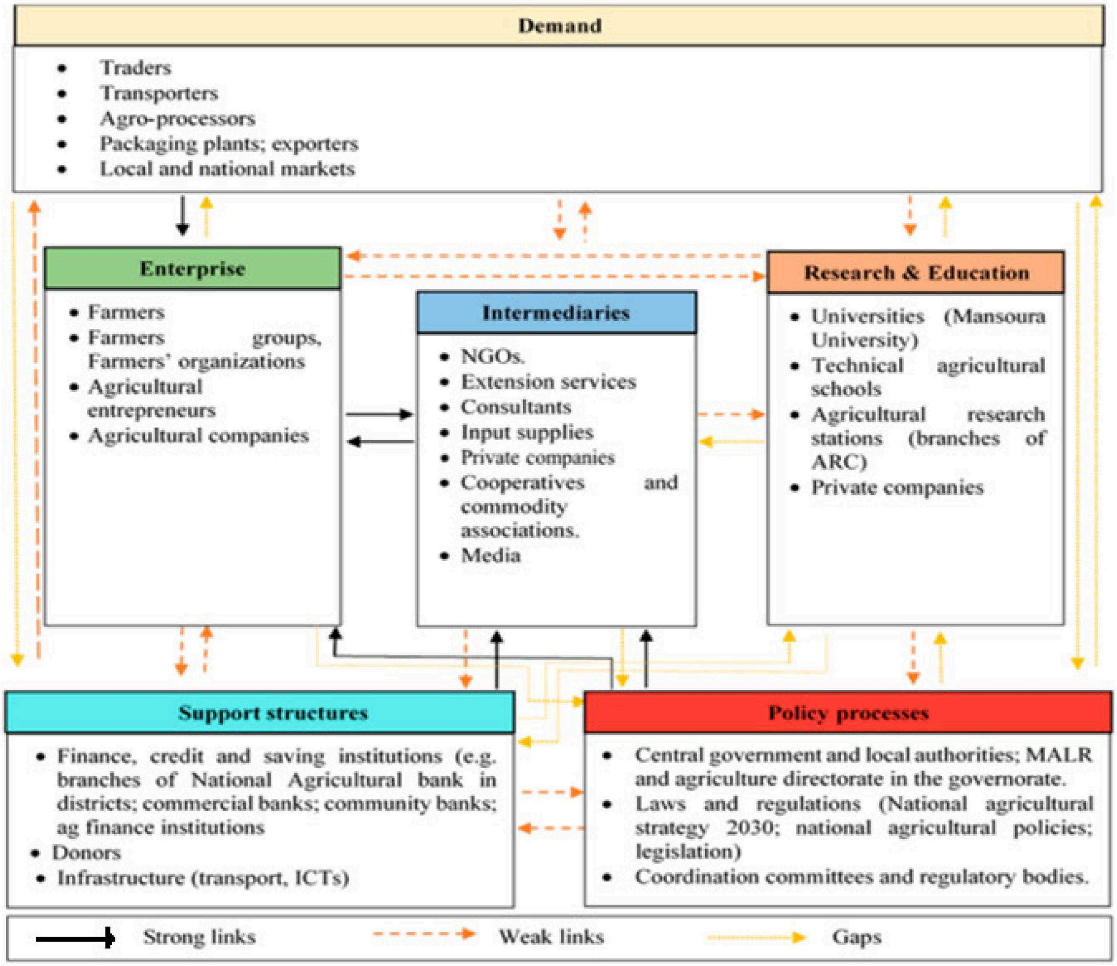

Figure 8. Agricultural knowledge and innovation system in Dakahlia governorate, Egypt. (Source: Zahran, Kassem, Naba, and Alotaibi [79]).

2.3. Sample

The present study targeted eight essential components. (1) The policy (P) component consists of agricultural directors at the directorate of agriculture in the governorate and its branches at the districts; (2) the research (R) component covers all researchers in eight public research stations (Horticulture Research Station, Soil, Water, and Environment Research Station, Plant Protection Research Station, Animal Production Research Station, Field Crops Research Station, Food Technology Research Station, Cotton Research Station, and Agricultural Engineering Research Station); (3) the secondary technical education (S) component has ten secondary agricultural schools in the governorate; (4) the higher education (H) component consists of one faculty of agriculture belonging to Mansoura University; (5) the extension (E) component encompasses public extension organization and its branches (extension department in the agricultural directorates at the district level and extension centers at the village level); (6) farmers' organizations (F) component constitutes 478 agricultural cooperatives in the governorate; (7) the private sector (V) component incorporates several private input suppliers, exporting companies, agricultural processing firms, and traders; (8) the agricultural credit (C) component embodies an agricultural bank at the governorate level and its branches at the district level (12) [79].

Based on the GTT approach guidelines, particularly about identifying gaps and critical paths for information, the difference in the number of respondents influences the assessment of the linkages' strength among components. Accordingly, we chose the same number of respondents from each system component. Eleven respondents corresponded to each component of the DG-AKIS, bringing the number to 88 respondents. This sample included the deputy minister of agriculture in the governorate and directors of agricultural directorates in the districts (policy component), directors of research stations and heads of departments (research component), head of departments from the Faculty of Agriculture, Mansoura University (Higher Education component), directors of agricultural technical schools (secondary education component), extension agents (extension component), headquarters of agricultural cooperatives (farmers' organization component), executive directors of the agricultural companies and input suppliers (private sectors component), and directors of agricultural bank branches (credit component).

2.4. Instrument

Data were collected by a standardized questionnaire accessible online during the period from June to August 2021. The link to the survey was sent to the actors' representatives via their e-mail and WhatsApp. The data collection tool contained two sections. The first section highlighted the linkages among the components in the DG-AKIS. The second section contained the respondents' evaluation of the information flow in the DG-AKIS.

2.5. Variable Measurement and Data Analysis

The respondents evaluated the strength of the linkages between their components and other components in the DG-AKIS on a four-point scale (none, weak, medium, and strong). The respondents that thought their components had linkages with other actors within the DG-AKIS expressed their opinions on the type of these linkages on a three-point scale (formal, informal, and mixed). Additionally, the respondents reporting that their component had a medium strength or strong linkages with the other actors in the DG-AKIS determined the mechanisms of these linkages. These linkages were adopted from [69,73], with slight modifications. Thus, the respondents in each actor picked the mechanisms constructed with other actors from a list of 20 mechanisms and divided them into the following six types of linkages: (1) planning and review: joint problem diagnosis, joint priority setting and planning, joint program development, and joint review and evaluation; (2) program activities: joint technology development, joint technology evaluation, joint technology demonstration, and joint technology diffusion; (3) resource utilization: exchange of personnel/staff rotation, joint use of facilities (e.g., laboratories), and sharing of financial resources and materials; (4) information: sharing of information, joint use of information sources (e.g., library and internet), joint reporting, joint publication of documents, and joint symposiums, workshops, and campaigns; (5) training: joint training of students and joint training of staff (short-term); (6) research activities: joint supervision of post-graduate students and joint participation in research projects.

Information flow was assessed depending on three indicators: the organization's capacity to receive new information from other organizations, its capacity to learn information (capacity to accumulate, store, and integrate all types of information), and its capacity to share information. The capacities of each component were evaluated on a three-point scale (weak, medium, and strong).

Data collected from the questionnaires were assigned, coded, and calculated according to the guidelines of the GTT approach identified from Sections 2.1.1–2.1.13. Due to the differences in responses among the respondents of each actor, we used the most frequent responses (mode) as the central location measurement for the respondents' assessment of the linkages and information flow within the DG-AKIS. Furthermore, Excel 2016 was utilized for generating the figures included in this paper.

3. Results

3.1. Assessment of Institutional Linkages within the DG-AKIS

3.1.1. Linkage Matrix

The GTT evaluated the linkages of DG-AKIS, as in Figure 9. The linkage matrix of DG-AKIS contained eight components. Agricultural cooperatives (F component), for example, the optimal matrix of DG-AKIS (Figure 9), had three types of organizational linkages: the first type (within-component linkages) appeared in linkages within F in the sixth row–sixth column. Put differently, the linkages among organizations dealt with agricultural cooperatives. The second type of linkages were between-component linkages. This type represented, for instance, the linkages between P and F denoted by PF in the first row and sixth column. Such interaction portrayed the linkages that P was declared to have with F. Similarly, linkages such as those between F and P shown by FP in the sixth row and the first column represented the linkages that the F had with P. Crucially, the linkages represented by PF were not necessarily the same as those represented by FP. This asymmetry was because actors had different drivers to engage with others in a linkage. Finally, the interactions formed between the two actors through binary linkages were the third type of linkages (multi-edged pathways). Assume that a pathway denoted by EFVC could be shown as E $\rightarrow$ F $\rightarrow$ V $\rightarrow$ C. This pathway between E and F included a sequence of binary linkages, beginning with linkages between E and F (EF), then those between F and V (FV), and eventually between V and C (VC). In this type of linkages (three-edged pathways), the pathway of EFVC contained three groups of binary linkages. In this example, sequencing is critical because the outcomes gained from a pathway of EFVC would not necessarily result in the same outcome of other pathways. According to the formula in Section 2.1, the total number of k-edged pathways within the DG-AKIS was 56.

P	PR	PH	PS	PE	PF	PV	PC
RP	**R**	RH	RS	RE	RF	RV	RC
HP	HR	**H**	HS	HE	HF	HV	HC
SP	SR	SH	**S**	SE	SF	SV	SC
EP	ER	EH	ES	**E**	EF	EV	EC
FP	FR	FH	FS	FE	**F**	FV	FC
VP	VR	VH	VS	VE	VF	**V**	VC
CP	CR	CH	CS	CE	CF	CV	**C**

Figure 9. The linkage matrix of agricultural knowledge and innovation system in Dakahlia governorate.

3.1.2. Coding Linkage Matrix

Figure 10A showed that binary linkages in DG-AKIS were coded with 1 if the linkage existed and 0 if not. We converted the coded matrix into a visual format, as depicted in Figure 10B. The same interactions in the coded matrix of DG-AKIS were presented differently (diagram), as shown in Figure 10C. For agricultural extension component, two-way linkages were observed with the other actors, whereas two-way linkages were visible among four components (policy, extension, private sector, and credit components) and agricultural cooperatives. However, the representatives of the research components noted that they were engaged with the agricultural cooperatives in linkages. The findings showed that the number of non-existed interactions among components was 21 linkages, representing 37.5% of the total potential binary linkages in the DG-AKIS.

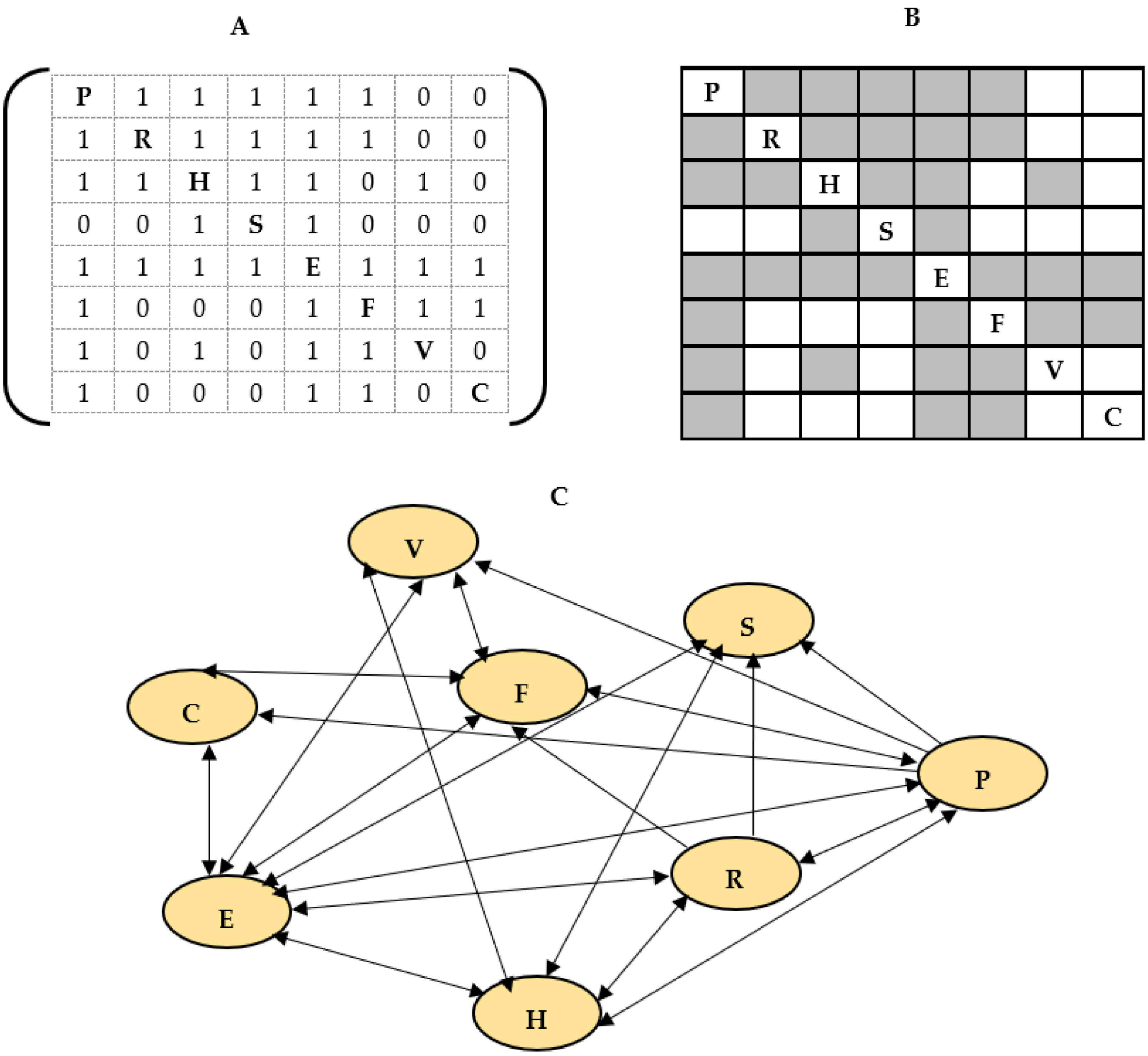

Figure 10. Coded matrix of agricultural knowledge and information systems in Dakahlia governorate (**A**), visual format of the matrix (**B**), and diagraph of binary linkages between components within the system (**C**).

3.1.3. The Refinement of Matrix

Using the coding identified in Section 2.1.3, the strength of linkages within DG-AKIS is given in Figure 11A,B. Regarding agricultural cooperatives, the findings proved that agricultural cooperatives had moderate two-way linkages with extension, private sector, and credit components. Differences in the estimation of the linkages' strength were observed between agricultural cooperatives (F) and policy (P), where the linkage FP was high and the linkage PF was moderate. However, representatives of the research component R reported that the strength between their organization and agricultural cooperatives (RF) was moderate, where the linkage (FR) was absent. Such linkage could be defined as a one-way linkage. Similarly, we could describe the strength of linkages among the other components in DG-AKIS. The types of linkages established between actors according to Figure 11 are available in Appendix A.

A

P	2	1	2	2	2	0	0
1	**R**	1	1	3	2	0	0
1	2	**H**	2	1	0	1	0
0	0	2	**S**	1	0	0	0
2	3	1	1	**E**	2	2	1
1	0	0	0	2	**F**	2	2
2	0	1	0	2	2	**V**	0
2	0	0	0	1	2	0	**C**

B

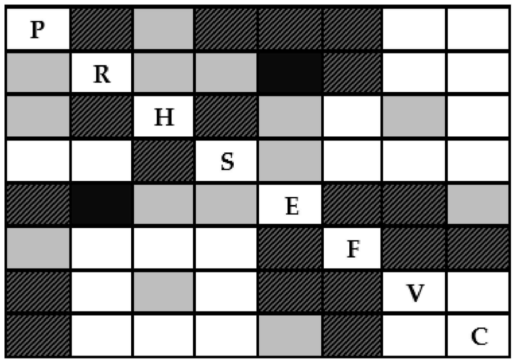

Figure 11. Refined matrix of agricultural knowledge and information system in Dakahlia governorate (**A**) and visual format of the matrix (**B**).

3.1.4. Adjusting Matrix

By pursuing the refined matrix (Section 2.1.4), Figure 12 depicts the adjusted matrix of DG-AKIS. In this matrix, the first row denotes the influence values of policy (P component) on the other actors (cause). In contrast, the first column indicates the effect values of other components on policy.

P	1.32	0.33	1.32	1.32	1.32	0	0
0.33	**R**	0.33	0.33	3	1.32	0	0
0.33	1.32	**H**	1.32	0.33	0	0.33	0
0	0	1.32	**S**	0.33	0	0	0
1.32	3	0.33	0.33	**E**	1.32	1.32	0.33
0.33	0	0	0	1.32	**F**	1.32	1.32
1.32	0	0.33	0	1.32	1.32	**V**	0
1.32	0	0	0	0.33	1.32	0	**C**

Figure 12. Adjusted matrix of the agricultural knowledge and information systems in Dakahlia governorate.

3.1.5. The Cause–Effect Structure of Matrix

Table 1 presents the cause–effect values of the various components within the DG-AKIS. The results showed that the extension component was the dominant component within the DG-AKIS. Specifically, the extension had the most influence on the other components and, simultaneously, the most affected component by other components within the DG-AKIS, having a total value of 7.95 for both cause and effect. For agricultural cooperatives (F), the results indicated that agricultural cooperatives ranked fourth for their real cause on the rest of the system, with a value of 4.29, while it ranked second for the total effect of other components on them, with a total value of 6.6. Contrarily, secondary education (S) and credit (C) were the most isolated components within the DG-AKIS. Figure 13 shows the scatter plot of cause and effect coordinates to present the cause–effect structure within the DG-AKIS visually.

Table 1. The cause–effect values of the components of the agricultural knowledge and information systems in Dakahlia governorate.

Components	Cause	Effect
Policy (P)	5.61	4.95
Research (R)	5.31	5.64
Higher Education (H)	3.63	2.64
Secondary Education (S)	1.65	3.3
Extension (E)	7.95	7.95
Farmer Organizations (F)	4.29	6.6
Private sector (P)	4.29	2.97
Credit (C)	2.97	1.65

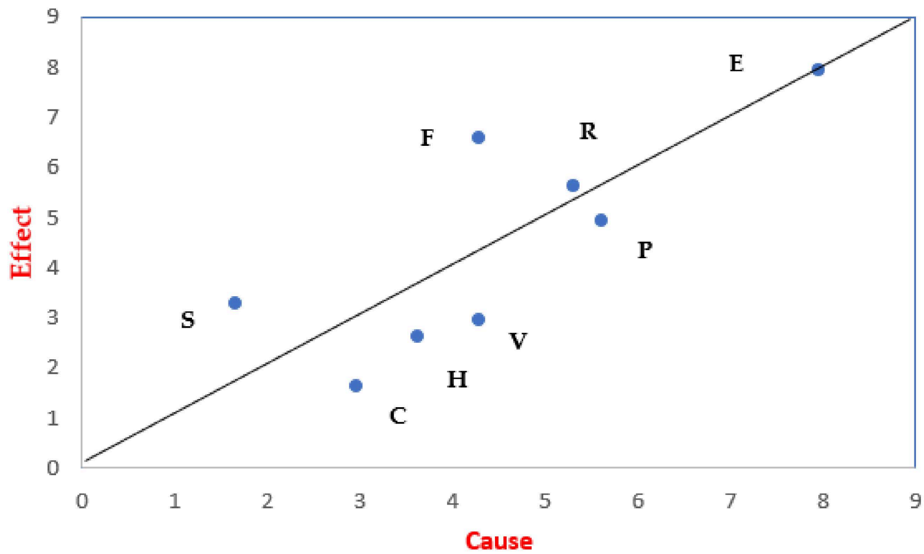

Figure 13. The cause–effect structure of the agricultural knowledge and innovation system in Dakahlia governorate.

3.1.6. Density of Matrix

Based on the method of the density of matrix calculation (Section 2.1.6), the density of interactions within the DG-AKIS was 0.625, suggesting that less than two-thirds of linkages existed between the components within the DG-AKIS. Considering 14 weak linkages between actors, the density of the matrix was reduced to 0.375.

3.2. Determining Gaps and Information Pathways within Agricultural Knowledge and Information Systems

3.2.1. Causal Relations Matrices

The findings in Figure 14 depicted that the linkages RP and ES were the most crucial linkages in the weak casual matrix. In contrast, the linkage (FC) had the first rank in the moderate causal matrix, and the linkage (ER) was the most crucial and strong interaction affirmed within the DG-AKIS. Meanwhile, the highest three linkages for the total causal relations were ER, FV, and EF, with the values of 29, 26, and 25, respectively.

A

P	2	5	3	2	2	0	0
8	**R**	5	5	1	5	0	0
6	4	**H**	3	6	0	7	0
0	0	2	**S**	6	0	0	0
2	0	5	8	**E**	1	2	6
6	0	0	0	2	**F**	0	1
4	0	5	0	4	2	**V**	0
5	0	0	0	6	2	0	**C**

B

P	14	4	10	12	14	0	0
6	**R**	10	6	8	12	0	0
10	12	**H**	14	8	0	8	0
0	0	12	**S**	6	0	0	0
12	8	8	6	**E**	12	12	6
10	0	0	0	12	**F**	14	18
12	0	8	0	12	14	**V**	0
12	0	0	0	8	14	0	**C**

C

P	6	0	3	9	3	0	0
0	**R**	0	0	18	0	0	0
0	3	**H**	3	3	0	0	0
0	0	9	**S**	0	0	0	0
9	21	3	0	**E**	12	9	0
0	0	0	0	9	**F**	12	3
0	0	0	0	2	6	**V**	0
0	0	0	0	3	6	0	**C**

D

P	22	9	16	23	19	0	0
14	**R**	15	11	27	17	0	0
16	19	**H**	20	17	0	15	0
0	0	23	**S**	12	0	0	0
23	29	16	14	**E**	25	23	12
16	0	0	0	23	**F**	26	22
16	0	13	0	19	22	**V**	0
17	0	0	0	17	22	0	**C**

Figure 14. Casual relation matrix of agricultural knowledge and innovation system in Dakahlia governorate: weak casual relations (**A**), moderate casual relations (**B**), strong casual relations (**C**), and total casual relations (**D**).

3.2.2. The Cause–Effect Structure of Causal Relations

The values of causal relations for various strength types of linkages within the DG-AKIS are in Table 2. Agricultural extension had strong interactions rather than weak or moderate interactions with other actors within the DG-AKIS. Based on the total value of cause and effect relations, agricultural extension ranked first. The component of agricultural cooperatives ranked third regarding their influence on the other components, with a total value of 87. Contrarily, they ranked second, with a total value of 105 as to the effect of the other components on them.

Table 2. The cause–effect structure of causal relations within the agricultural knowledge and innovation system in Dakahlia governorate.

Components	Weak Linkages		Moderate Linkages		Strong Linkages		Total Linkages	
	Cause	Effect	Cause	Effect	Cause	Effect	Cause	Effect
Policy (P)	14	31	54	62	21	9	89	102
Research (R)	24	6	42	34	18	30	84	70
Higher education (H)	26	22	52	42	9	12	87	76
Secondary education (S)	8	19	18	36	9	6	35	61
Extension (E)	24	27	64	66	54	44	142	138
Farmer organizations (F)	9	12	54	66	24	27	87	105
Private sector (V)	15	9	46	34	8	21	70	64
Credit (C)	13	7	34	24	9	3	56	34

Figure 15 illustrates coordinates of the cause–effect structure for the total causal relations between the actors investigated within the DG-AKIS and has three important areas. The first area is located at the 45° line, where the cause equals influence (cause = effect). The component located in this region is highly interactive with the rest of the system's components if its coordinates are in the upper-right corner of Figure 15. Contrarily, the reaction of the component might be minimal in the system if its coordinates are close to the coordinates (0,0). The second area is below the 45° line, where the degree of a component's influence is greater than the degree of effect (cause > effect). The component is dominant on the other components in the system. The third area is above the 45° line degree, where the degree of a component's influence is less than its influence (cause < effect), showing that the component is sub-ordinal to the rest of the system components. Figure 15 shows that the extension component is nearly in the first area, proving its interactivity with other components. The findings also revealed that the research and higher education components might be moderately dominant in the DG-AKIS. In contrast, the agricultural cooperatives and policy components were subordinate components in the systems, and secondary education and credit components were less interactive.

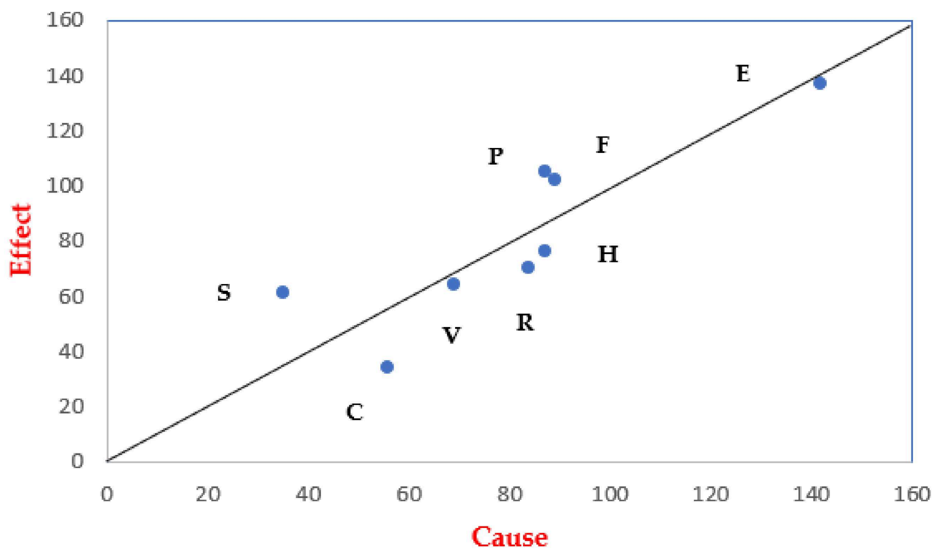

Figure 15. The cause–effect structure for the total causal relations between components of the agricultural knowledge and innovation system in Dakahlia governorate.

3.2.3. Critical Information Gaps and Pathways

By classifying actors within the DG-AKIS based on the total causal relations, the reduced causal connections matrix determines critical information gaps or meaningful causal relations, as depicted in Figure 16. The reduced causal relations matrix included eight critical linkages: HF, HE, RE, RF, RP, HP, EF, and EP. Hence, the vital gaps within the DG-AKIS (Figure 16) were the influence of higher education on agricultural cooperatives and extension, the effect of research on extension and agricultural cooperatives, and the influence of research on farmers and agricultural cooperatives. Seven out of eight vital gaps existed and had varying values, while the linkage between higher education and agricultural cooperatives was absent in the DG-AKIS. The reduced causal matrix for agricultural cooperatives specified that research and higher education components were the external components within the DG-AKIS. Contrarily, agricultural cooperatives were the internal component within the system. Therefore, the essential causal pathways always begin from external components (extension or research components) and end with the internal (agricultural cooperatives), implying that the vital pathways are HEF and REF. Thus, the first pathway (HEF) could be interpreted as follows: higher education supplied innovations to extension, which finally disseminated such information to agricultural cooperatives. Similarly, the second pathway (REF) meant that research produced innovations and delivered them to extension, then extension dispersed them to agricultural cooperatives.

P							
14	**R**			27	17		
16		**H**		17	0		
			S				
23				**E**	25		
					F		
					22	**V**	
							C

Figure 16. The reduced casual matrix of agricultural knowledge and innovation system in Dakhalia governorate.

3.3. Assessment of Information Flow within Agricultural Knowledge and Information System

3.3.1. The Information Flow Matrix

Following the steps identified in Section 2.1.10, we formed the information flow matrix to evaluate information flow within the DG-AKIS, as seen in Figure 17. This matrix defines the capacity of the actors within the DG-AKIS to receive information, learn, and share it.

$\mathbf{P(\lambda^P)}$	$\sigma^P\theta^R$	$\sigma^P\theta^H$	$\sigma^P\theta^S$	$\sigma^P\theta^E$	$\sigma^P\theta^E$	0	0
$\sigma^R\theta^P$	$\mathbf{R(\lambda^R)}$	$\sigma^R\theta^H$	$\sigma^R\theta^S$	$\sigma^R\theta^E$	$\sigma^R\theta^F$	0	0
$\sigma^H\theta^P$	$\sigma^H\theta^R$	$\mathbf{H(\lambda^H)}$	$\sigma^H\theta^S$	$\sigma^H\theta^E$	0	$\sigma^H\theta^V$	0
0	0	$\sigma^S\theta^H$	$\mathbf{S(\lambda^S)}$	$\sigma^S\theta^E$	0	0	0
$\sigma^E\theta^P$	$\sigma^E\theta^R$	$\sigma^E\theta^H$	$\sigma^E\theta^S$	$\mathbf{E(\lambda^E)}$	$\sigma^E\theta^F$	$\sigma^E\theta^V$	$\sigma^E\theta^C$
$\sigma^F\theta^P$	0	0	0	$\sigma^F\theta^E$	$\mathbf{F(\lambda^F)}$	$\sigma^F\theta^V$	$\sigma^F\theta^C$
$\sigma^V\theta^P$	0	$\sigma^V\theta^H$	0	$\sigma^V\theta^E$	$\sigma^V\theta^F$	$\mathbf{V(\lambda^V)}$	0
$\sigma^C\theta^P$	0	0	0	$\sigma^C\theta^E$	$\sigma^C\theta^F$	0	$\mathbf{C(\lambda^C)}$

Figure 17. The information flow matrix of agricultural knowledge and innovation system in Dakhalia governorate.

3.3.2. The Capacity Matrix

The respondents' assessment of the organizations' capacities in receiving, learning, and sharing information is shown in Table 3. The estimations of the components' capacities essentially ranged from medium to low for these three indicators. Agricultural extension had strong capacities to receive and to share information, while it had a weak capacity to learn from other components. Furthermore, research and agricultural cooperatives' components had medium capacities in all indicators. The capacity matrix considered the capacities' weight values described in Section 2.1.11 (Figure 18).

Table 3. Average capacities to receive (θ), learn (λ), and share (σ) information in the agricultural knowledge and innovation system in Dakahlia governorate.

Components	Capacity to Receive (θ)	Capacity to Learn (λ)	Capacity to Share (σ)
Policy (P)	Medium (m = 0.66)	Weak (w = 0.33)	Medium (m = 0.66)
Research (R)	Medium (m = 0.66)	Medium (m = 0.66)	Medium (m = 0.66)
Higher Education (H)	Medium (m = 0.66)	Strong (s = 1)	Medium (m = 0.66)
Secondary Education (S)	Weak (w = 0.33)	Weak (w = 0.33)	Weak (w = 0.33)
Extension (E)	Strong (s = 1)	Weak (w = 0.33)	Strong (s = 1)
Farmer Organizations (F)	Medium (m = 0.66)	Medium (m = 0.66)	Medium (m = 0.66)
Private sector (V)	Medium (m = 0.66)	Medium (m = 0.66)	Strong (s = 1)
Credit (C)	Weak (w = 0.33)	Medium (m = 0.66)	Weak (w = 0.33)

P(0.33)	0.4	0.4	0.2	0.7	0.4	0	0
0.4	**R(0.66)**	0.4	0.2	0.7	0.4	0	0
0.4	0.4	**H(1)**	0.2	0.7	0	0.4	0
0	0	0.2	**S(0.33)**	0.3	0	0	0
0.7	0.7	0.7	0.3	**E(0.33)**	0.7	0.7	0.3
0.4	0	0	0	0.7	**F(0.66)**	0.4	0.2
0.7	0	0.7	0	1	0.7	**V(0.66)**	0
0.2	0	0	0	0.3	0.2	0	**C(0.66)**

Figure 18. The capacity matrix of agricultural knowledge and innovation system in Dakhalia governorate.

3.3.3. The Adjusted Capacity Matrix

The capacity matrix of information flow within the DG-AKSIS was adjusted following the technique supplied in Section 2.1.12, as shown in Figure 19. This matrix examines how fluid the information in the DG-AKIS is. For agricultural extension, the highest information flow was observed from research to extension and vice versa with the value of 2.1.

P	0.8	0.4	0.4	1.4	0.8	0	0
0.4	**R**	0.4	0.2	2.1	0.8	0	0
0.4	0.8	**H**	0.4	0.7	0	0.4	0
0	0	0.4	**S**	0.3	0	0	0
1.4	2.1	0.7	0.3	**E**	1.4	1.4	0.3
0.4	0	0	0	1.4	**F**	0.8	0.4
1.4	0	0.7	0	2	1.4	**V**	0
0.4	0	0	0	0.3	0.4	0	**C**

Figure 19. The reduced casual matrix of agricultural knowledge and innovation system in Dakhalia governorate.

3.3.4. The Information Flow Structure

Table 4 depicts the information flow structure for the supply and receipt components within the identified DG-AKIS. Interestingly, the results showed that agricultural cooperatives ranked second after the extension component to supply information to other components in the DG-AKIS with the value of 4.8. About receiving information from other components, agricultural cooperatives were the highest component, having a value of 7.6. To present the supply–receipt structure within the DG-AKIS, the scatter plot of supply and receipt coordinates is available in Figure 20.

Table 4. Supply and receipt values of the components in the agricultural knowledge and information systems in Dakahlia governorate.

Components	Supply	Receipt
Policy (P)	4.4	3.8
Research (R)	3.7	3.9
Higher Education (H)	2.6	2.7
Secondary Education (S)	1.3	0.7
Extension (E)	8.2	7.6
Agricultural cooperatives (F)	4.8	3
Private sector (P)	2.6	5.5
Credit (C)	0.7	1.1

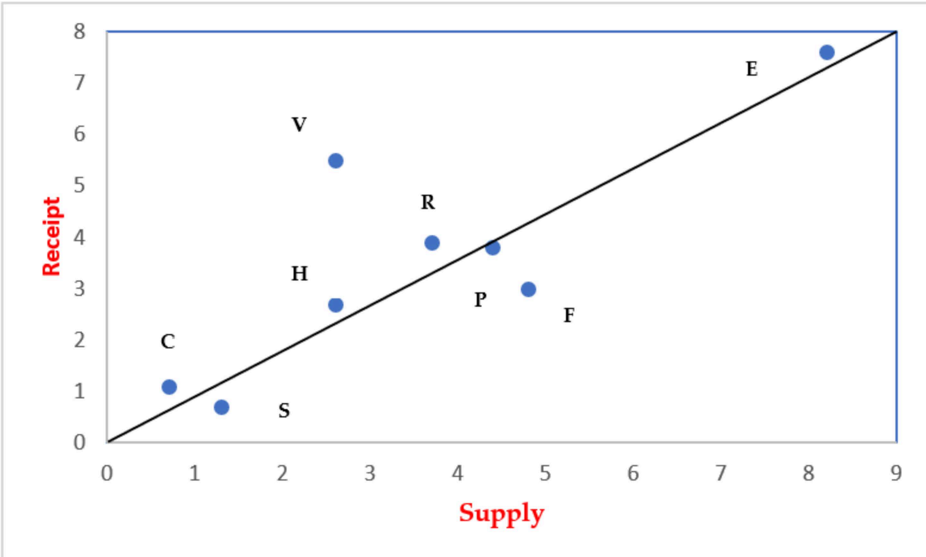

Figure 20. The supply–receipt structure of information between components of the agricultural knowledge and innovation system in Dakahlia governorate.

4. Discussion

This study assesses the DG-AKIS by highlighting three main aspects: assessment of institutional linkages, identification of critical information pathways, and evaluation of information flow. The study findings will support the fifth theme of the Egyptian strategy of the sustainable agricultural development 2030 (reinforcing the interactions between various components within the AKIS) [80].

4.1. Assessment of Institutional Linkages

Analysis of institutional linkages within the DG-AKIS indicates that the agricultural cooperatives are sub-ordinate components because their influence on other actors was less than others' influence on them. This result is not surprising because agricultural cooperatives are the final target of all actors within the AKIS, and, concurrently, they are the last knowledge user. This result is in line with those of previous studies conducted in the field of AKIS in Egypt [81,82]. This result reflects the pressing need to manipulate the role of agricultural cooperatives in innovation intermediation within AKIS. Therefore, Gouët and Van Paassen [83] argued that agricultural cooperatives bring synergy to agricultural innovation efforts by connecting various actors. Furthermore, enhancing the interactions between agricultural cooperatives and other actors in the AKIS is critical to fostering conditions for innovation and to support the food supply chain. This conclusion was supported by Jarzębowski et al. [84] in their analysis of sustainable food chains. He found that short food supply chains require closer and more intensive interactions among producers, consumers, and other relevant actors to facilitate food distribution and link agricultural cooperatives with markets. Nonetheless, new linkage mechanisms are necessary to coordinate actors in long value chains to guarantee food quality and safety at national and international levels [85].

4.2. Critical Information Pathways

The GTT approach results specify that the critical information pathways for agricultural cooperatives within the DG-AKIS are HEF and REF, stressing the relevance of activating the interactions among the agricultural cooperatives and extension, research, and higher education components. This may be attributed to the fact that the extension component has a more crucial influence as an interactive component in the DG-AKIS, and the research component is critical as a dominant component in developing and diffusing innovations in coordination with extension to agricultural cooperatives. Specifically, the absence of the linkage HF is notable in the DG-AKIS. Thus, an information gap exists to support the two critical information pathways. In this context, Hekkert and Negro [43], in their analysis of innovation systems, argued that higher education institutions, research organizations, and agricultural companies are three fundamental actors involved in the innovation process in the agricultural sector. The participation of different actors in knowledge development and dissemination meets farmers' diverse needs and affects market dynamics positively [37]. Moreover, the diversity of knowledge service providers boosts group dynamics such as community engagement, collaboration, participation, and joint-learning between farmers and others, contributing to accelerating knowledge generation and promoting the knowledge transfer beyond the traditional link (farmer–extension) [16,38]. Dutrénit et al. [86] verified that policies should support agricultural cooperatives, organize training programs, and promote linkages among other actors in the AKIS to improve the farmer–university linkage.

4.3. Evaluation of Information Flow

The reduced causal matrix (Figure 15) reveals the merit of keeping the strong linkages, building and strengthening the absent linkages, and closing information pathway gaps. Nevertheless, the selection between binary linkages and information pathways to alleviate information flow within the DG-AKIS is debatable. Therefore, Abdel-Ghany [81] reported that this selection would depend on utilizing such linkages. If the goal was to achieve strong linkages, one would select the pathway of three-edged linkages. However, if the purpose was to have direct linkages, the binary linkages would be the choice. As to information flow, the results within the DG-AKIS (Table 4 and Figure 19) disclose that the agricultural cooperatives manage to accelerate information flow among actors efficiently, besides the extension component, implying that both extension and agricultural cooperatives can cooperate in supplying information. This result is in line with the results of Yang, Klerkx, and Leeuwis [32], who showed the effectiveness of agricultural cooperatives in China as an intermediary organization in faciliating information among actors of AKIS. Therefore, this study suggested strenthening the functions of agricultural cooperatives, as intermediary organizations should be a target for policy interventions. By reinforcing this role, the exchange and sharing of information between agricultural cooperatives and other actors can be frequent and quick [59,68]. Moreover, the cooperative's function in innovation intermediation can lead to faster decisions, thus increasing their competitive advantage in the market [40]. This conclusion was supported by Ji et al. [87] in their analysis of the sustainability of agricultural cooperatives in China, who found that cooperative's function in innovation intermediation directly influences the sustainability performance of agricultural cooperatives and enhances the ability of agricultural cooperatives to address sustainability issues in different fields.

However, this study has some limitations that require acknowledgment. We have gathered data from one governorate. Thus, we cannot generalize the results to include other governorates within Egypt or other countries. The evaluation of institutional linkages and information flow has depended on the self-report of the representatives of actors, implying that this approach relies on what the respondents believe to be accurate, biasing the results of the assessment of interactions. Even though collecting data using online surveys is handier than traditional face-to-face interviews, it does not allow us to collect qualitative data on the obstacles of building or strengthening interactions.

5. Conclusions

This paper focuses on the eight actors regarding institutional linkages and information flow within the AKIS in Egypt. This study contributes to the literature by evaluating how public and private actors can engage with agricultural extension and agricultural cooperatives, on what level of information flow, and where the information pathway gaps remain. The findings suggest that enhancing interaction within the DG-AKIS requires building 21 linkages and strengthening 14 weak linkages. The extension is the most interactive component in terms of institutional linkages and information flow, while the secondary education and credit components are the lowest. Even though agricultural cooperatives still need to enhance their linkages in terms of number and the strength of connections to activate their potential role in innovation intermediation, their capacity in providing and receiving information is high compared to other actors within the DG-AKIS. The GTT approach has eight critical binary linkages (HF, HE, RE, RF, RP, HP, EF, and EP) and two information pathways (HEF and REF) to enhance information flow within the DG-AKIS.

The present study provides six beneficial implications for policies to activate the DG-AKIS, particularly, and the innovation system in general. First, decision-makers should raise awareness among the various actors within the DG-AKIS as to the relevance of linkages, the potential and suitable mechanisms between them, and of determining the obstacles facing these actors in establishing or strengthening the linkages. Second, defining the shortest paths to connect the components of the system contributes to achieving as much networking as possible between those components. Third, both credit and secondary education need reforming to promote interaction with agricultural cooperatives and other components. Fourth, the potential utilization of the extension component as an intermediary and interactive organization within the DG-AKIS to empower agricultural cooperatives is needed to increase their influence on other components and information sharing with other components. This role is manageable by organizing a learning-process approach within an action-learning framework for building capacity, mentoring and supporting the agricultural cooperatives in planning and implementation stages and facilitating effective partnership meetings with other stakeholders in the AKIS. Fifth, closing the information gaps guarantees better information flow among the actors beyond the traditional path (REF), explicitly building and strengthening the connections between higher education institutions and agricultural cooperatives. Finally, using results gained from the GTT approach to reform the DG-AKIS, future studies could investigate the approach adopted in this research in other countries by focusing on the national level or by analyzing the AKIS regarding the specific agricultural field or specific innovation.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Mechanisms of linkages established between actors within the agricultural knowledge and information system in Dakahlia governorate.

Linkages	Mechanisms
P → R	- Priority setting and planning - Review and evaluation - Information sharing - Workshops, seminars, etc.
P → S	- Information sharing - Workshops, seminars, etc.
P → E	- Priority setting and planning - Review and evaluation - Information sharing - Workshops, seminars, etc. - Reporting
P → F	- Information sharing - Workshops, seminars, etc.
R → E	- Technology diffusion - Information sharing - Reporting - Problem diagnosis - Technology demonstration - Training of staff
R → F	- Information sharing - Problem diagnosis - Technology diffusion - Technology demonstration
H → R	- Information sharing - Use of facilities - Workshops, seminars, etc. - Supervision of post-graduate students - Participation in research projects - Publication of documents - Use of information sources - Technology development
H → S	- Information sharing - Workshops, seminars, etc. - Training of staff - Training of students
S → H	- Information sharing - Workshops, seminars, etc. - Training of staff - Training of students
E → P	- Information sharing
E → R	- Information sharing
E → F	- Information sharing - Problem diagnosis - Technology diffusion - Technology demonstration

Table A1. *Cont.*

Linkages	Mechanisms
E → V	- Information sharing
F → E	- Information sharing - Problem diagnosis - Technology diffusion - Technology demonstration
F → V	- Purchasing farm inputs—Marketing agricultural products
F → C	- Loans
V → P	- Information sharing
V → E	- Information sharing - Workshops, seminars, etc.
V → F	- Purchasing farm inputs - Marketing agricultural products - Information sharing - Training of farmers
C → P	- Information sharing
C → F	- Information sharing - Loans

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